# Hyper-dimensional time-series data analysis with reservoir computing networks to predict plasma profiles in tokamak


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Collaboration: DIII-D Team

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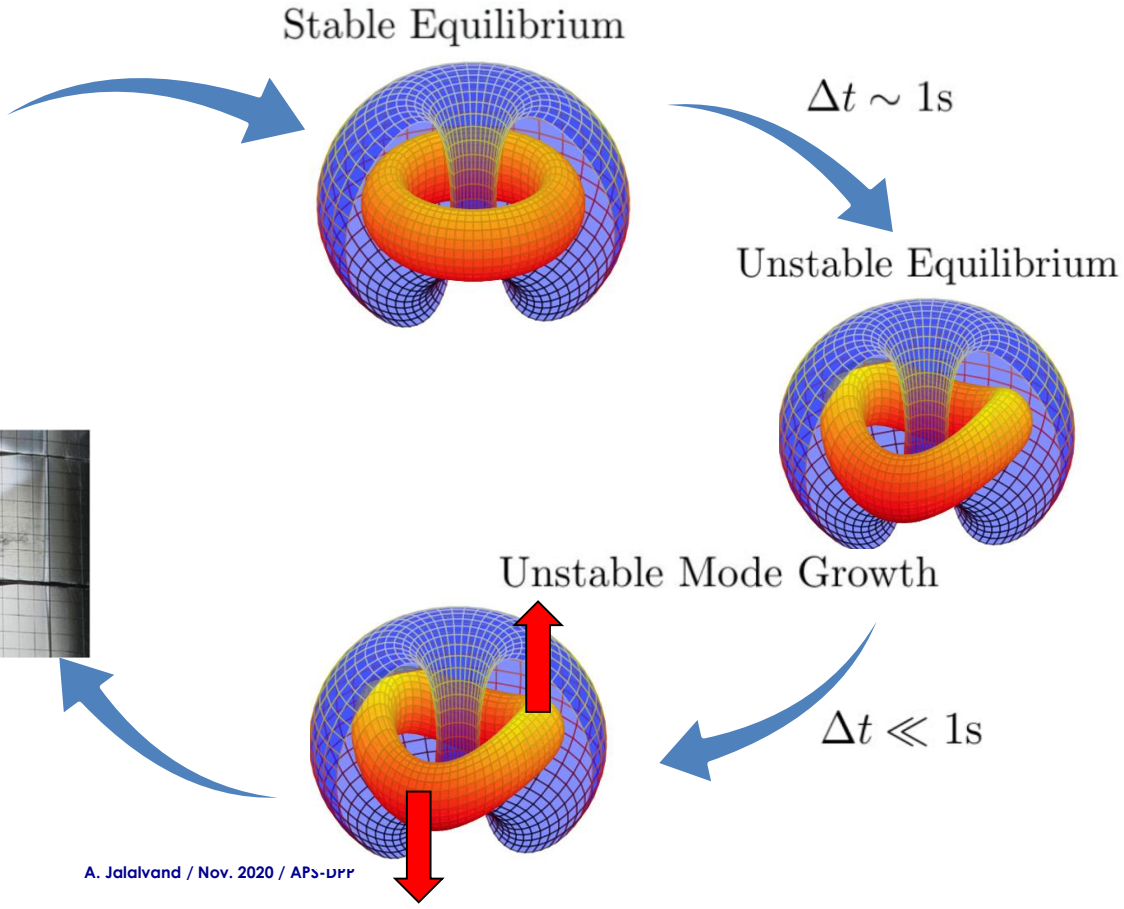
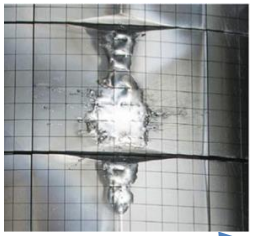
# Outline

- What is tokamak?
- why data-driven models for plasma condition monitoring?
- What is Reservoir Computing Network?
- Real-time adaptive RCN models for plasma profile prediction

# Plasma condition monitoring in Tokamaks



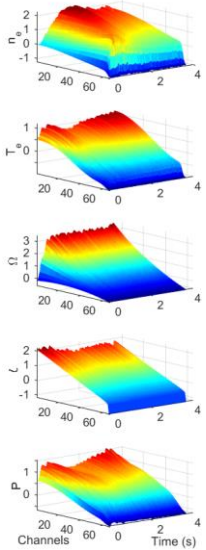
**Example Wall Damage from JET**

Matthews et al. Physica Scripta, T167, 2016

**ITER and future reactors need disruption avoidance solutions**

# Data-Driven Transport Model for DIII-D

Given state (and actuators), can we predict how plasma will evolve on transport timescales (~100-200ms)?

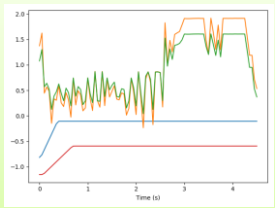



***x(t)***

- **Electron temperature ($T_e$)**
- **Electron density ($n_e$)**
- **Safety factor ($q$)**
- **Rotation ($\Omega$)**
- **Pressure ($P$)**

***u(t)***

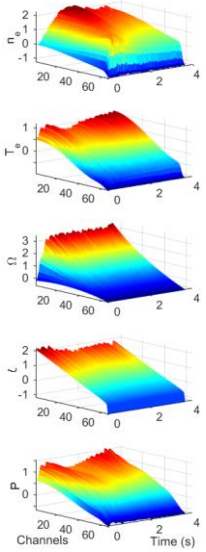
- $P_{injected}$
- $T_{injected}$
- $I_p$
- $\langle ne \rangle_{target}$



$$x(t+\Delta t) = x(t) + f[x(t), u(t)]$$

***f[x(t), u(t)]***

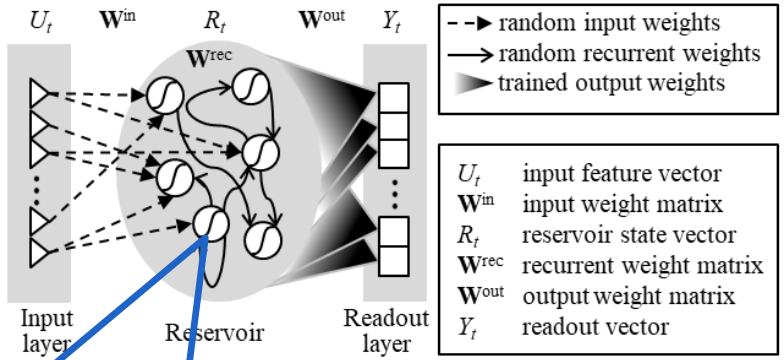
- $T_e$
- $n_e$
- $q$
- $\Omega$
- $P$

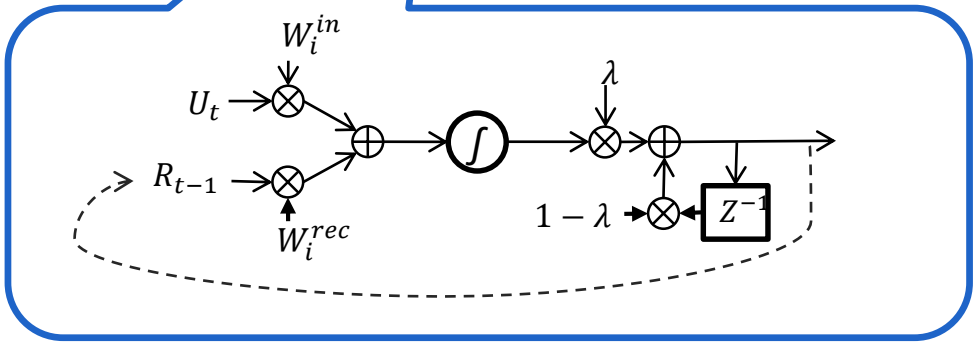


# What is Reservoir computing network*?

* Jaeger H. (2001) The "echo state" approach to analyzing and training recurrent neural networks. GMD Report 148, GMD - German National Research Institute for Computer Science

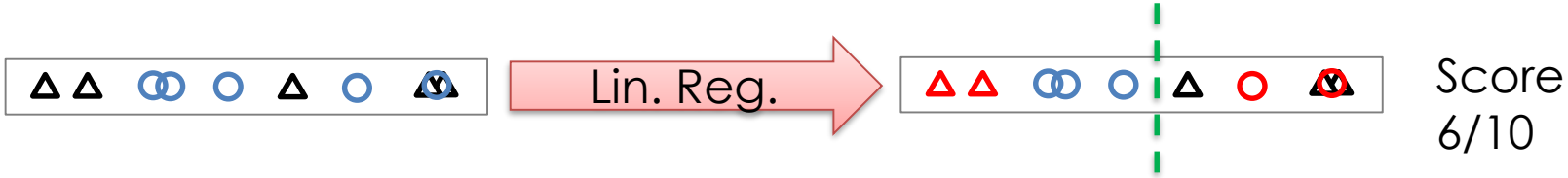
- **Reservoir computing network (RCN)**
  - Recurrent neural network
  - Randomly connected early layers.
  - Only Last layer is trained using linear regression.
  - Suitable for time-series data analysis
  - **Much faster and easier training** procedure compared to DNNs.



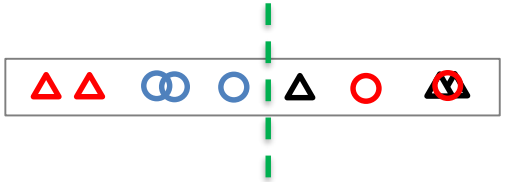

The model can be **adapted** to the new data in **real-time**!
Adaptation takes only **100ms** on a laptop CPU!

# How does RCN work?



# How does RCN work?

Lin. Reg.



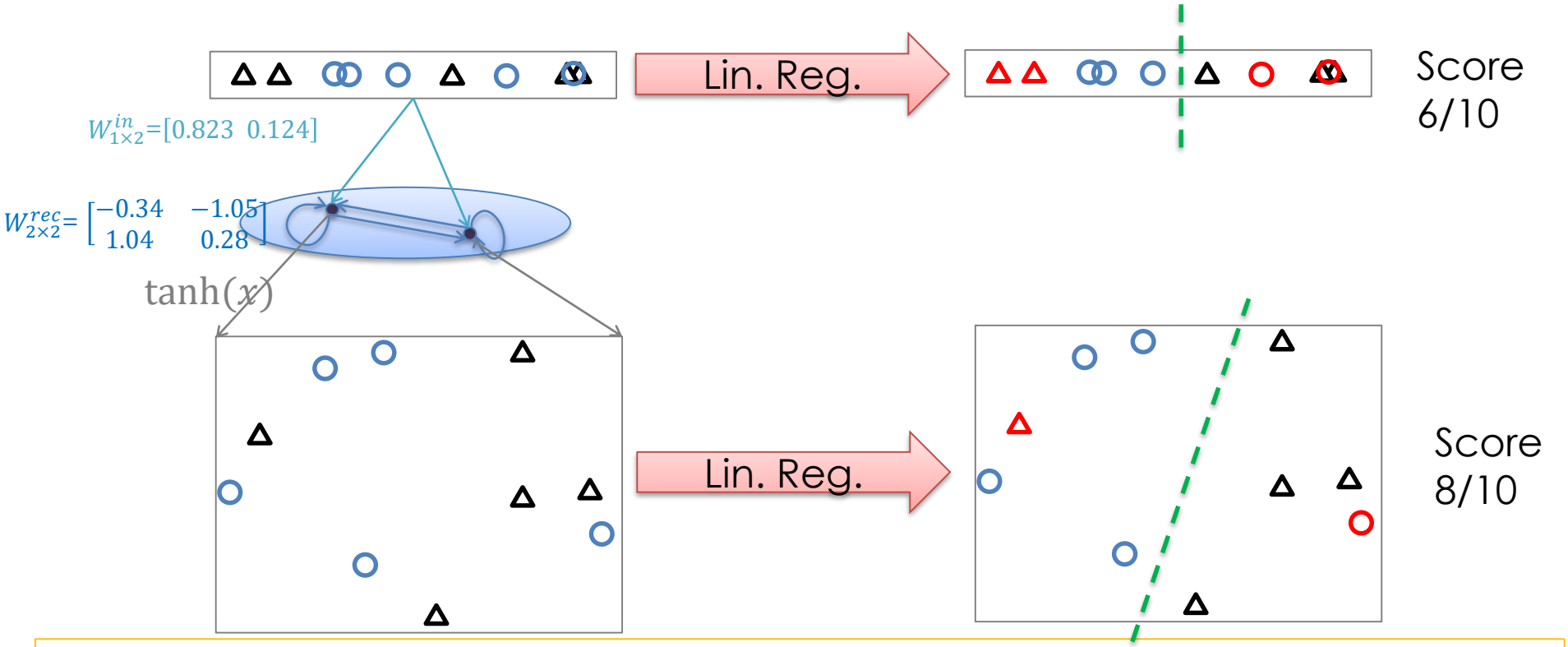
Score
6/10

$W^{in}_{1\times2}$=[0.823 0.124]

$W^{rec}_{2\times2}$= $\begin{bmatrix} -0.34 & -1.05 \\ 1.04 & 0.28 \end{bmatrix}$

$W^{in}$ and $W^{rec}$ are set randomly

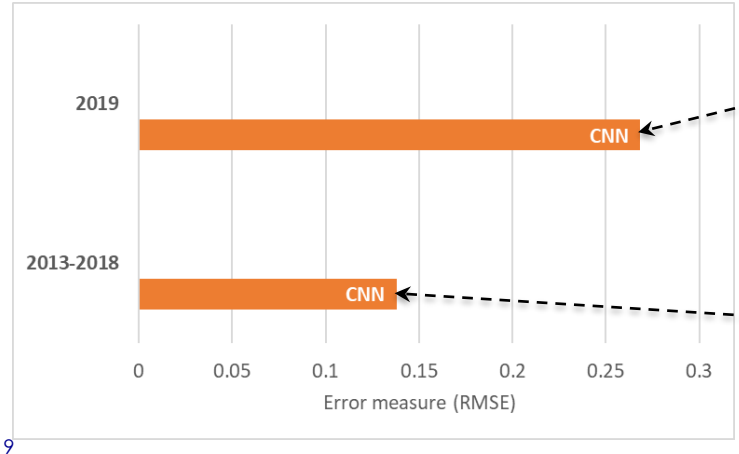
# How does RCN work?




RCN randomly projects the inputs to a (much) larger non-linear feature space.

# Adaptive Data-driven Profile Prediction Models

| | CNN/LSTM |
|---|---|
| Training | 5h on GPU |
| Performance | SOTA |



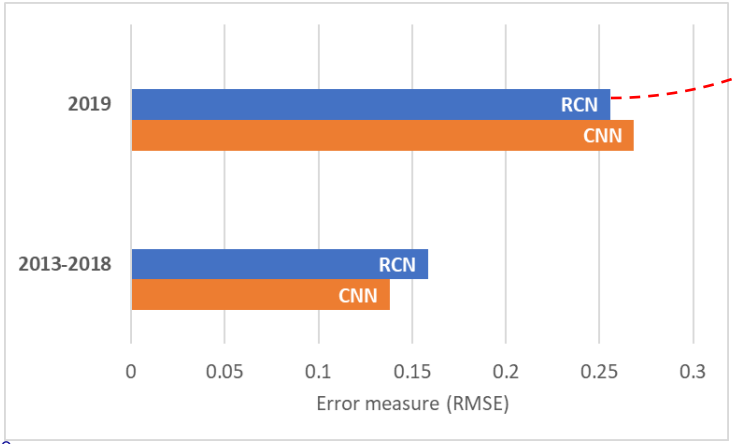

Train a on the data from **2013-2018**

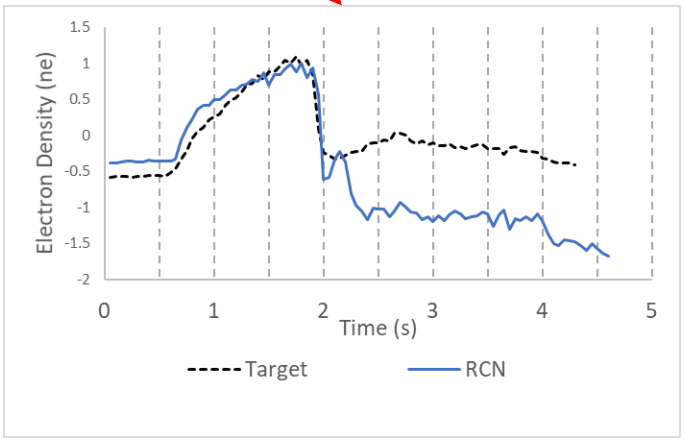
Predict the profiles for **2019**

Predict the profiles for **the same period**

# Adaptive Data-driven Profile Prediction Models
## By means of Reservoir Computing Network

| | CNN/LSTM | RCN |
|---|---|---|
| Training | 5h on GPU | 45s on CPU |
| Performance | SOTA | Close to DNN |



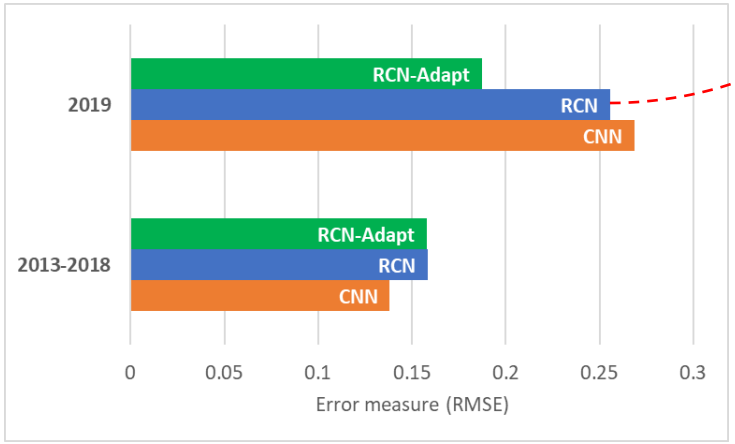



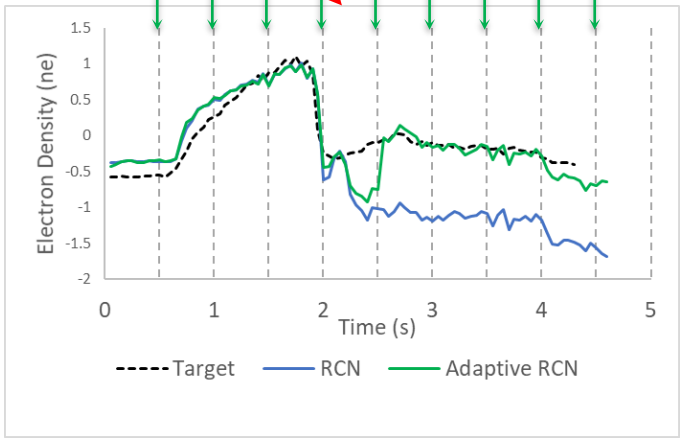
# Adaptive Data-driven Profile Prediction Models
## By means of Reservoir Computing Network *

* A. Jalalvand, J. Abbate, R. Conlin, G. Verdoolaege, E. Kolemen,
"**Real-Time and Adaptive Reservoir Computing with an Application to Profile Prediction in Fusion Plasma**",
IEEE Trans. on Neural Net. & Learning Systems, 2020.

| | CNN/LSTM | RCN |
|---|---|---|
| Training | 5h on GPU | 45s on CPU |
| Performance | SOTA | Close to DNN |
| Adaptation | Difficult | Easy (100ms) |

Real-time Adapting every 500ms



# Conclusion

- RCN performs similar to state-pf-the-art DNN models in predicting plasma profiles.
- Easy and fast training procedure of RCN is an important asset for quick adaptation to the new environment.

Thank you!